39. — THE ATMOSPHERE OF MARS

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The available data concerning Mars are far too few to permit the development of a definitive model of the atmosphere of that planet. We urgently need new observations. Until now these models are likely to display wide variance. There are, however, a few general conclusions that one can draw concerning the lower atmosphere of Mars, especially the layers responsible for haze and clouds.

I shall not concern myself about the chemical composition of the Martian atmosphere. I suppose that it consists mainly of nitrogen, with a few per cent of carbon dioxide and argon. I shall not object to adding a small amount of molecular oxygen.

I am concerned, however, with water vapor content since that substance is capable of condensing out to form liquid or crystal fogs. The quantity of water in an atmosphere is often expressed as the number of centimeters of precipitable water. And the somewhat vague standard of reference is the amount of water vapor above Mount Wilson on an average clear winter day. We shall not be far wrong if we adopt 1 centimeter of precipitable water as the reference standard.

We may reasonably suppose that about ten times as much water exists on Mars in the solid state as exists in the form of atmospheric vapor. We may further assume that the polar caps occupy about one-tenth of the surface of Mars. Then, if the atmosphere of Mars were to contain the standard reference figure of one centimeter of precipitable water, the depth of accumulated ice or, rather, hoar frost over the poles, would be about 100 times greater, or one meter.

Actually this figure must be much too large. Dunham estimated it as about 1000 times smaller. Hence, if this were so, the depth of

the layer of polar frost would be only a millimeter. I think that Dunham's figure, arrived at without consideration of the curve growth, is perhaps ten times too low. I conclude that the thickness of the layer of polar frost is not more than a few centimeters.

Adopting 0.1 millimeter as the amount of precipitable water in the atmosphere and assuming that it is distributed through one scale height of about 20 km, we calculate a vapor pressure of 5 dynes. This figure is the equilibrium vapor pressure over ice at a temperature of 190°K. The air, of course, may not be saturated, so that higher temperatures are permissible. But, if we are to form an ice fog in an atmosphere of such a low vapor pressure, the temperature of the surrounding air must be less than 190°K. The vapor pressure is very sensitive to small changes in temperature. Lowering the temperature by only 12 degrees will reduce the vapor pressure by a factor of 10. At the theoretical adiabatic gradient for the atmosphere of Mars, a difference of 12 degrees will take place in only 4 kilometers. A layer of ice fog will thus be extremely thin and it will occur in that region of the atmosphere where the temperature ranges between about 180°K to 190°K.

The height of that layer will vary with latitude, season, and time of day. The rarefied atmosphere of Mars would stimulate radiation cooling during the night, with possible formation of a temperature inversion. One may therefore expect under certain conditions a double ice layer, one near the ground and another at higher elevation. Indeed, the white markings often seen on the eastern terminator may well be a layer of frost on the surface of the planet, a thin deposit that quickly sublimes as the day advances.

It is tempting to suppose that the thin layer of crystal fog is responsible for the appearance of the blue image of Mars. A thin layer is necessary to account for the sharp edges of the blue images. And Rayleigh scattering does the rest. Particles some 2×10^{-5} in diameter are indicated. A column of 2×10^8 particles per cm^2 will give adequate optical depth in the violet and yet be transparent in the visible. This amount of material is extremely small, slightly less

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than 10^{-5} grams per cm². This is much less than the 10^{-5} grams per cm² of precipitable water previously postulated. The discrepancy disappears if we set the cloud layer forming at about 160°K, with a partially saturated atmosphere underneath. And we cannot completely dismiss the possibility that the fog may consist of frozen carbon dioxide.

Now return to other questions related to the atmosphere. The redness of Mars, its low albedo, and the visibility of surface markings in the red and yellow indicate that the total amount of atmosphere is small. Dollfus sets the value of 0.22 in terms of the equivalent scattering power of the earth's atmosphere. And since at least half of this scattering must be attributed to haze, the total atmosphere of Mars must be less than one-tenth that of the earth.

Although some scientists have ascribed the red color of Mars to its atmosphere, I see no justification for this hypothesis. Mars is red because its surface is red. The red images show marked darkening to the limb. For this effect I see no explanation but absorption by a low and fairly thick layer of dust. The dust particles must be larger than 1 micron to minimize the Rayleigh scattering. According to Stokes' formula, particles of this size near the surface of Mars would acquire a speed of sedimentation of 3×10^{-2} centimeters per second. A layer three kilometers thick, therefore, would take about 10^7 seconds or about four months to settle out. This slow rate of fall for the absorbing red layer is thus consistent with the permanence of the polar caps and the failure of the dust to cover it.

We have concluded, then, that the atmosphere of Mars contains two layers of particulate matter, a thick layer of large dust particles near the surface and a very thin layer of fine particles above, perhaps well above, the layer of dust. We have implied that this upper layer consists of fine ice crystals. Certainly this suggestion is consistent with the association between the thin atmospheric clouds and the underlying polar caps. The clouds, for example, persist for some time after the solid cap has sublimed. But the

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ice crystal hypothesis is not without difficulty. Ice crystals would seem to have a very high reflecting power and should, therefore, lead to a higher violet albedo than that determined for Mars. I should prefer dark absorbing clouds, rather than ice crystals. Smoke would be about right, like the blue smoke from the lighted end of a cigarette, rather than the white smoke from the unlit end. Perhaps the blue clouds consist of very fine dust and their association with the polar regions may be attributed to some effect of atmospheric circulation that causes the particles to concentrate in these areas.

None of these hypotheses accounts satisfactorily for the phenomenon known as « blue clearing », the improved visibility of surface features in blue light near the time of opposition. I have long felt that this « clearing » may arise from improved contrast at the planet's surface, near opposition, when rays of sunlight falling upon a roughened surface can escape from the interstices through which they entered.

I have noticed a similar effect from airplanes flying over desert areas in the south western U. S. The effect is especially pronounced near sunset. The shadow of the plane on the ground is surrounded by a bright halo 2 or 3 degrees in diameter. Within this halo, the details of the surface markings are much more clearly seen than outside of the halo.